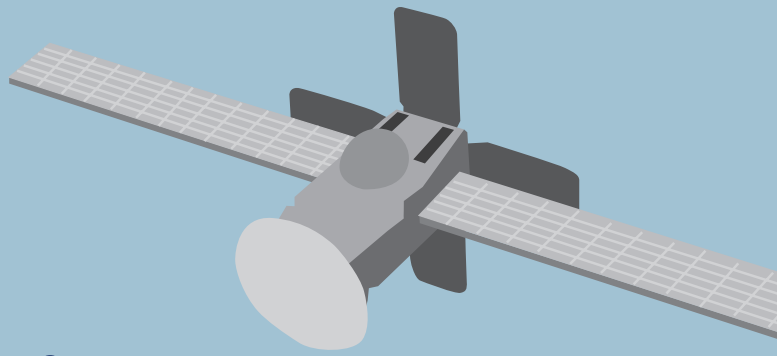
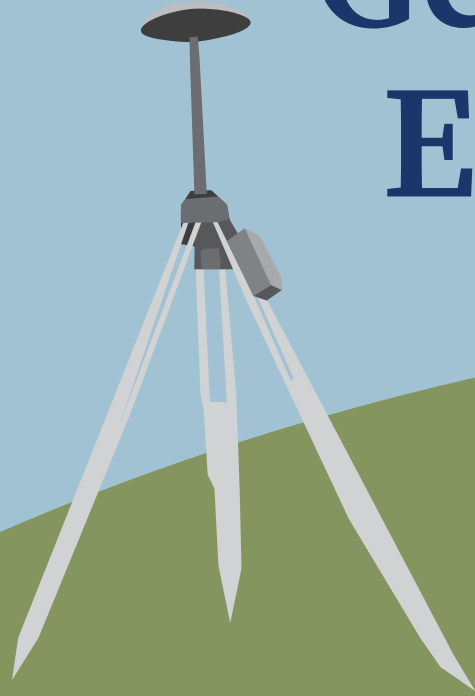


ASCE MANUALS AND
REPORTS ON
ENGINEERING PRACTICE
NO. 152



Surveying and Geomatics Engineering



Principles,
Technologies,
and Applications

Prepared by the Surveying Committee

EDITED BY

Daniel T. Gillins, Ph.D., P.L.S.

Michael L. Dennis, Ph.D., P.E., P.L.S.

Allan Y. Ng, P.L.S.



UTILITY ENGINEERING
& SURVEYING
INSTITUTE

Surveying and Geomatics Engineering

Other Titles of Interest

Applied GPS for Engineers and Project Managers, by Clement A. Ogaja. (ASCE Press 2011). This book introduces civil engineers—especially those who are not already licensed surveyors—to the fundamental principles of global positioning technology (ISBN 978-0-7844-1150-6).

CORS and OPUS for Engineers: Tools for Surveying and Mapping Applications, edited by Tomás Soler (ASCE/Geomatics Division 2011). This collection of 22 articles assembles the latest thinking on the use of two advanced services—CORS and OPUS—for obtaining accurate positional coordinates to use in high-accuracy surveying (ISBN 978-0-7844-1164-3).

NAVSTAR Global Positioning System Surveying, by the U.S. Army Corps of Engineers (ASCE Press 2000). The U.S. Army Corps of Engineers Technical Engineering and Design Guide No. 28 provides technical specifications and procedural guidance for surveying with the NAVSTAR GPS (ISBN 978-0-7844-0353-2).

Surveying and Geomatics Engineering

Principles, Technologies, and Applications

Sponsored by
The Surveying Committee of the
Surveying and Geomatics Division of the
Utility Engineering and Surveying Institute of the
American Society of Civil Engineers and the
National Geodetic Survey

Edited by
Daniel T. Gillins, Ph.D., P.L.S.
Michael L. Dennis, Ph.D., P.E., P.L.S.
Allan Y. Ng, P.L.S.



UTILITY ENGINEERING
& SURVEYING
INSTITUTE

Library of Congress Cataloging-in-Publication Data

Names: Gillins, Daniel T., editor. | Dennis, Michael L., editor | Allan Y. Ng, editor.

Title: Surveying and geomatics engineering : principles, technologies, and applications / edited by Daniel T. Gillins, Michael L. Dennis, Allan Y. Ng.

Description: Reston, Virginia : American Society of Civil Engineers, [2022] | Series: ASCE manuals and reports on engineering practice ; no. 152 | "Sponsored by the Surveying Committee of the Surveying and Geomatics Division of the Utility Engineering and Surveying Institute of the American Society of Civil Engineers and the National Geodetic Survey." | Includes bibliographical references and index. | Summary: "MOP 152 provides a comprehensive yet general overview to help support education and inform practicing engineers on the important role of the surveying engineer"-- Provided by publisher.

Identifiers: LCCN 2021059081 | ISBN 9780784416037 (paperback) | ISBN 9780784484005 (pdf)

Subjects: LCSH: Surveying. | Geomatics.

Classification: LCC TA545 .S8535 2022 | DDC 526.9--dc23/eng/20220114

LC record available at <https://lcn.loc.gov/2021059081>

Published by American Society of Civil Engineers

1801 Alexander Bell Drive

Reston, Virginia 20191-4382

www.asce.org/bookstore | ascelibrary.org

The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration (NOAA) or the Department of Commerce.

Any statements expressed in these materials are those of the individual authors and do not necessarily represent the views of ASCE, which takes no responsibility for any statement made herein. No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE. The materials are for general information only and do not represent a standard of ASCE, nor are they intended as a reference in purchase specifications, contracts, regulations, statutes, or any other legal document. ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefor. The information contained in these materials should not be used without first securing competent advice with respect to its suitability for any general or specific application. Anyone utilizing such information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

ASCE and American Society of Civil Engineers—Registered in US Patent and Trademark Office.

Photocopies and permissions. Permission to photocopy or reproduce material from ASCE publications can be requested by sending an email to permissions@asce.org or by locating a title in the ASCE Library (<http://ascelibrary.org>) and using the "Permissions" link.

Errata: Errata, if any, can be found at <https://doi.org/10.1061/9780784416037>.

Copyright © 2022 by the American Society of Civil Engineers.

All Rights Reserved.

ISBN 978-0-7844-1603-7 (print)

ISBN 978-0-7844-8400-5 (PDF)

ISBN 978-0-7844-8422-7 (ePub)

Manufactured in the United States of America.

27 26 25 24 23 22 1 2 3 4 5

MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and April 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a “standard,” however, nor is it so elementary or so conclusive as to provide a “rule of thumb” for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person’s observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable the committee is under the direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each manual shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, so that its merit may be definitely understood.

In February 1962 (and revised in April 1982), the Board of Direction voted to establish a series titled “Manuals and Reports on Engineering Practice” to include the manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such manual or report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past manuals. Numbering would be consecutive and would be a continuation of present manual numbers. In some cases of joint committee reports, bypassing of journal publications may be authorized.

A list of available Manuals of Practice can be found at <http://www.asce.org/bookstore>.

CONTENTS

FOREWORD	XVII
PREFACE	XIX
ACKNOWLEDGMENTS	XXI
1. ENGINEERING SURVEYING WITHIN ASCE	1
<i>Gene V. Roe</i>	
Introduction.....	1
Geomatics and Geospatial Engineering	1
Surveying Engineer Today.....	2
Professional Licensing and Certification.....	3
Chapter Topics	4
References	5
2. GEODESY AND GEODETIC COMPUTATIONS	7
<i>Earl F. Burkholder</i>	
Introduction.....	7
Brief History of Geodesy	7
Geometrical Elements of Geodesy	9
Geodetic Coordinate Systems	12
Models Used in Geometrical Geodesy	15
Geodetic Forward and Inverse Computations.....	16
Physical Geodesy.....	17
Datums	21
Horizontal Datums.....	21
Vertical Datums.....	25
New Datums—The Modernized National Spatial Reference System	26
References	27
3. MAP PROJECTIONS AND LOCAL COORDINATE SYSTEMS	29
<i>Michael L. Dennis</i>	
Introduction.....	29
Map Projections	30
Map Projections Appropriate for Surveying and Engineering.....	32
Defining Parameters of Projected Coordinate Systems	34
Map Projection Distortion	37
Projected Coordinate Systems	44
State Plane Coordinate System.....	44

Universal Grids: Universal Transverse Mercator and Universal Polar Stereographic Coordinate Systems	56
The “Grid versus Ground” Problem.....	58
Methods for Reducing Map Projection Distortion	61
Low-Distortion Projection Coordinate Systems.....	65
Nonprojected Local Coordinate Systems.....	74
Local Geodetic Horizon Systems	74
Nongeoreferenced Local Coordinate Systems	79
Summary.....	81
References.....	82
4. LOCAL, REGIONAL, AND GLOBAL COORDINATE TRANSFORMATIONS.....	85
<i>Michael L. Dennis</i>	
Introduction.....	85
Equation-Based Transformations	86
Local Horizontal and Vertical Transformations	86
Horizontal Calibration/Localization.....	93
Vertical Calibration/Localization.....	96
Summary Discussion on Calibration/Localization.....	98
Global Equation-Based Coordinate Transformations.....	99
International Terrestrial Reference System	102
World Geodetic System of 1984.....	105
Three Frames of the North American Datum of 1983.....	106
Grid-Based Coordinate Transformations.....	108
NADCON (Geometric Coordinate Transformations).....	109
National Geodetic Survey Hybrid and Gravimetric Geoid Models (Vertical Transformations).....	118
VDatum (Vertical Transformations).....	119
Combined Equation- and Grid-Based Transformations	120
Summary.....	130
References.....	131
5. ANALYSIS AND ADJUSTMENT OF OBSERVATIONAL ERRORS	135
<i>Charles D. Ghilani</i>	
Introduction.....	135
Types of Errors	135
Population versus Sample.....	137
Least-Squares Adjustments.....	141
Error Propagation.....	142
Weights.....	144
Preparing Data for an Adjustment.....	148
Postadjustment Statistics.....	149
Postadjustment Blunder Detection	152
Statistical Methods of Determining Map Accuracy.....	153
Conclusions	155
References.....	156
6. SATELLITE-BASED SURVEYING TECHNOLOGY.....	157
<i>Jan Van Sickle</i>	
Brief Overview of Global Positioning System.....	157
Global Positioning System Segments	157
Space Segment	157

Control Segment	158
User Segment	160
Global Positioning System Signals.....	160
Codes.....	160
Wavelength and Frequency.....	160
NAV Messages.....	161
Pseudorandom Noise Codes	161
P(Y) Code.....	161
C/A Code	161
Error Sources	162
Ionospheric Effect (d_{ion}).....	162
Satellite Clock Bias (dt).....	162
Receiver Clock Bias (dT).....	162
Orbital Bias (d_{ρ}).....	162
Tropospheric Effect (d_{trop}).....	163
Multipath.....	163
Receiver Noise	163
Differential Global Positioning System versus Relative Positioning.....	163
Solutions	163
Single Point.....	165
Relative Positioning	166
Postprocessing	166
Correlation of Biases	166
Global Positioning System Survey Planning.....	166
Independent Lines.....	169
Station Data Sheet.....	171
Observation Logs.....	172
Global Navigation Satellite System Surveying Techniques	174
Static	174
Real-Time Kinematic.....	174
Real-Time Networks	176
Precise Point Positioning.....	176
Global Positioning System Modernization and Global Navigation	
Satellite System.....	178
GPS Satellite Blocks.....	178
Global Navigation Satellite Systems.....	180
Future	182
References.....	182
7. LEVELING AND TOTAL STATIONS.....	185
<i>N. W. J. Hazelton</i>	
Introduction to Levels and Leveling.....	185
Leveling Instruments and Equipment.....	186
Levels.....	186
Tripods	187
Leveling Rods.....	188
Leveling Rod Bubbles	188
Core Leveling Procedures	188
Setting up the Level.....	188
Reading the Rod	190
Two-Peg Test	191

Base Leveling	193
General Leveling.....	193
Recording Methods	196
Basic Leveling Processes.....	201
Errors in Leveling.....	203
Orthometric and Dynamic Corrections.....	205
Adjustment	208
Introduction to Total Stations	209
Design of Modern Total Stations	209
Total Station Equipment	210
Tripods	210
Data Collectors.....	210
Prisms.....	210
Orientation.....	212
Total Station Extensions.....	213
Reflectorless.....	213
Robotic	213
Imaging.....	214
Targeting.....	214
Scanning.....	214
Global Navigation Satellite System Connection	214
Programmable.....	215
Setting Up the Total Station	215
Tripod	215
Instrument	215
Optical Plummet.....	215
Laser Plummet.....	216
Final Leveling.....	216
Heights.....	217
Zeroing Instrument	218
Basic Total Station Procedures	218
Measuring Horizontal Angles	218
Reducing Horizontal Angles	219
Measuring Vertical Angles	220
Reducing Vertical Angles	222
Deflection of the Vertical	222
Measuring Distances.....	224
Reducing Distances	225
Refraction and Curvature.....	226
Point Codes	227
Electronic Distance Measurement Calibration.....	228
Total Station Processes	229
Traversing.....	229
Networks	230
Topographic Surveys	230
Layout Work.....	231
References.....	231
8. TERRESTRIAL LASER SCANNING	233
<i>Michael J. Olsen</i>	
Introduction.....	233
Overview	236

Key References	236
Applications in Civil Engineering.....	236
System Types.....	242
Data Structure and Scan Patterns.....	242
Data Quality Considerations	244
Differences to Airborne and Mobile Lidar.....	248
TLS Workflows.....	248
Planning and Preliminary Site Surveys.....	248
Field Procedures	250
Leveling/Inclination Sensors.....	252
Field Notes.....	253
Data Backup Strategies	253
Care of Equipment	253
Registration Strategies	253
Calibration Procedures	254
Transformation Points versus Validation Points.....	255
Rigid-Body Coordinate Transformations.....	255
Coordinate Systems.....	258
Direct Georeferencing.....	258
Target-Based Registration.....	258
Cloud-to-Cloud Surface Matching.....	262
Mixed Approaches	264
Comparison	264
Registration Quality Control	264
Processing Workflows.....	272
Filtering.....	272
Density Filters	273
Topographic Mapping and Digital Terrain Modeling.....	274
Geometric Modeling	276
Feature Extraction.....	278
Processing Quality Control	283
Analyses.....	283
Visualization Analysis	283
Change Analysis	284
Clash Detection.....	286
Reverse Engineering	286
Intensity Analyses	286
Visibility Analyses.....	287
Structural Analyses	287
Best Practices	287
Future Changes.....	288
Acknowledgments	288
References.....	289
9. MOBILE TERRESTRIAL LASER SCANNING AND MAPPING.....	303
<i>Michael J. Olsen, Jaehoon Jung, Erzhuo Che, Chris Parrish</i>	
Introduction.....	303
Key References.....	303
System Components	306
Applications	307
Project Workflow	310

Planning	310
Preliminary Site Surveys	312
Data Acquisition	312
Georeferencing	312
Post-Processing	318
Computations/Analysis	322
Packaging/Delivery	322
Indoor Mobile Mapping Technology	322
Sensors for Indoor Mapping	323
SLAM Algorithms	324
Indoor Mobile Mapping Systems	327
Looking Forward	329
Acknowledgments	330
References	330
10. AERIAL SURVEYING TECHNOLOGY	341
<i>Michael J. Starek, Benjamin E. Wilkinson</i>	
Aerial Photogrammetry	341
Introduction	341
Cameras	342
Camera Distortion and Calibration	344
Basic Principles of Aerial Photogrammetry	345
Analytical Photogrammetry	347
Stereoplotters	350
Digital Elevation Models	351
Orthophotos	352
Project Planning	352
Aerial Laser Scanning	353
Introduction	353
Fundamental Principles	354
Determination of Position and Orientation	355
Properties of Aerial Laser Scanners	357
Topographic and Bathymetric Aerial Laser Scanners	358
Ranging Modalities	359
Beam Divergence	362
Laser Scanner Characteristics	362
Operational Aspects of Airborne Laser Scanning	364
Project Planning and Execution	364
Calibration	365
Quality Control and Accuracy Reporting	365
Data Processing	366
Data Products	367
Aerial Laser Scanning Performance	372
Error Budget	372
Advantages and Limitations of Aerial Laser Scanning	372
Unmanned Aircraft Systems	373
Introduction	373
Platforms and Sensors	374
Aerial Mapping with Unmanned Aircraft Systems	376
Mission Planning	376
Flight Design	377

Ground Control.....	382
Structure-from-Motion Photogrammetry	384
Unmanned Aircraft Systems-Structure-from-Motion Accuracy.....	386
Regulations.....	388
References.....	389
11. SURVEY CONTROL.....	393
<i>Daniel T. Gillins</i>	
Introduction.....	393
Horizontal, Vertical, or Both	394
Local Control.....	395
Geodetic Control.....	395
Active Control: National Oceanic and Atmospheric Administration (NOAA)	
Continuously Operating Reference Stations (CORS) Network	396
Active Control: Real-Time Network.....	401
Passive Control	402
Project Planning and Control.....	406
Setting New Control.....	409
Common Tools for Control Surveying	412
Geodetic Leveling Specifications.....	412
GNSS Control Surveying Guidelines: NOS NGS-58 and 59	412
Online Positioning User Service-Static.....	413
Online Positioning User Service-Rapid Static.....	414
Online Positioning User Service-Projects.....	415
Other Online Tools for Global Navigation Satellite System Processing.....	419
Adjustments and Evaluating Control.....	421
References.....	422
12. CONSTRUCTION SURVEYS	425
<i>Marlee A. Walton</i>	
Introduction.....	425
Before Construction.....	425
During Construction	426
After Construction.....	426
Horizontal and Vertical Control	427
Horizontal Control	427
Vertical Control	428
Construction Survey Task Sequence.....	429
Construction Survey Equipment.....	429
Field Notes.....	430
Construction Staking and Layout	431
Construction Staking Equipment.....	431
Construction Stakes.....	432
Reference Stakes	433
Slope Stakes	433
Grade Stakes.....	433
Site Layout Stakes.....	434
Structure Stakes	434
Right-of-Way Markers and Property Boundary Monuments.....	434
Earthwork Computations.....	434
As-Built Surveys	435

Machine Guidance and Control	435
References	439
13. SURVEY RECORDS.....	441
<i>Andrew C. Kellie</i>	
Introduction.....	441
Typical Survey Records	442
Company Standards as Survey Records	442
Construction Documents as Survey Records	442
Numeric Survey Records.....	443
Graphic Survey Records.....	445
Project Monumentation	447
Control Diagram.....	447
Mark Descriptions.....	448
Report of Survey.....	449
Summary.....	449
References.....	450
14. INFORMATION SYSTEMS IN CIVIL ENGINEERING.....	451
<i>Yelda Turkan, Dimitrios Bolkas, Jaehoon Jung, Matthew S. O’banion, Michael Bunn</i>	
Introduction.....	451
Geographic Information Systems.....	451
Building Information Modeling.....	452
Coordinate Systems in Geographic Information Systems/Building	
Information Models.....	454
Geographic Information Systems/Building Information Modeling	
Technologies	455
Computing Hardware and Software	455
From Point Clouds to Models.....	456
Immersive Visualization Technologies.....	457
Key Data Models	459
Key Data Types for Geographic Information Systems.....	459
Key Data Types for Building Information Modeling	461
Database.....	465
Databases in Geographic Information Systems	465
ID Fields.....	467
Joining and Relating Tables.....	467
Query Languages	469
Fields and Data Types.....	469
Common Spatial Operators and Geoprocessing Tools	470
Vector Operators	471
Topology	472
Raster Operators	473
Automated Feature Identification in Imagery	474
Interpolation Techniques.....	475
Topographic Operations.....	476
Example Geographic Information Systems Applications and Analyses.....	478
Example Building Information Modeling Applications	479
Building Information Modeling for Infrastructure Projects.....	479
Building Information Modeling and Light Detection and Ranging for	
Project Progress Monitoring.....	482

Scan-to-Building Information Modeling: Converting Point Clouds
 into Building Information Models 482
 References 484

**15. PROFESSIONAL SERVICES AND DESIGN PROFESSIONALS’
 AGREEMENTS 489**
David E. Woolley, Lisa D. Herzog

Introduction..... 489
 Contracts 101—The Basic Legal Principles..... 489
 Offer..... 490
 Acceptance..... 490
 Consideration..... 490
 Consent 491
 Capacity 491
 Legality..... 492
 Writing 492
 Key Provisions for Design Professionals’ Contracts 492
 Certifications, Guarantees, and Warranties 493
 Incorporation by Reference of Another Contract or Document 493
 A Design Professional’s Indemnity Obligation Must Be Negligence Based..... 494
 Standard of Care in Negligence..... 494
 Indemnity—Duty to Defend..... 495
 Indemnity—Limit Indemnitees..... 496
 Liability to Owners Based on Claims by Third Parties..... 496
 Indemnity—Joint and Several Liability 496
 Indemnity—Limits on Liability to Policy Limits 497
 Ownership and Use of Design Professional’s Work Including Copyright 498
 Include a Hold Harmless Clause in the Design Professional’s Contract 500
 Scope of Work 500
 Other Important Areas to Cover in a Design Professional’s Agreement 500
 Examples of Design Professionals’ Agreements 502
 Design Professional’s Employment Agreement 502
 Appendix 503
 References 535

INDEX 537

FOREWORD

Surveying engineering has been at the heart of the National Geodetic Survey (NGS) since our founding as the Survey of the Coast in 1807 by President Thomas Jefferson. The purpose, as stated by Congress, was “...for completing an accurate chart of every part of the coasts....” In 1878, under the name of the United States Coast and Geodetic Survey (USC&GS), our mission expanded to include the entire country. We continued under that name for nearly 100 years, until the creation of the National Oceanic and Atmospheric Administration (NOAA) in 1970. Today, the geodetic work of the USC&GS continues under the name NGS, as an office within NOAA’s National Ocean Service.

With this long and distinguished history, NGS is often touted as our nation’s first civilian *science* agency. Although our name has changed and the breadth of our work has grown, our core mission remains the same: to support surveying and mapping in the United States. We accomplish this mission through the creative application of scientific principles and mathematics to solve practical problems for the benefit of society—the very definition of *engineering*.

The NGS engineering ethos is an enduring connection not just to civil engineering in general but also to the American Society of Civil Engineers (ASCE) in particular. This connection is best exemplified by Major William Bowie, a geodetic engineer and Chief of the USC&GS Division of Geodesy from 1915 until his retirement in 1936. Bowie joined ASCE in 1917 and founded the ASCE Surveying and Mapping Division in 1926, serving as Chair until his death in 1940. The name was changed to Surveying Engineering Division in 1986, and then to Geomatics Division in 1997. It was renamed Surveying and Geomatics Division (SGD) in 2015, along with the creation of the ASCE Utility Engineering and Surveying Institute (UESI). As a UESI division, SGD carries forward the spirit of what Bowie started, by ensuring that surveying engineering remains an integral part of civil engineering.

This manual of practice is an extension of Major Bowie’s foresight and passion. Founded on science, rooted in mathematics, and focused on modern practical applications, it serves as a general but comprehensive reference for practicing engineers, surveyors, and other geospatial professionals. Within its pages, topics range from the fundamentals of geodesy, coordinate systems, least-squares adjustments, and error propagation through the latest innovations in satellite, terrestrial, mobile, and airborne technologies. It provides best practices for these technologies, as well as for other topics, such as establishing geodetic control, performing construction surveys, and employing geographic and building information systems in civil engineering. Two of the manual’s three editors are NGS employees who authored three of the 15 chapters herein. All other chapters are written by authors who are experts in their respective fields. This manual is a unique compilation of professional and practical material—all located in this one magnificent source.

A common thread running through the manual is the importance of the National Spatial Reference System (NSRS) to modern geospatial applications. The NSRS serves as the

foundation for civilian surveying and mapping in the United States and its territories. It forms an essential link between the geospatial professions and NGS, whose mission is to define, maintain, and provide access to the NSRS.

The NSRS has never been more important than it is today for ensuring that the work products of surveying engineering are correctly georeferenced and meet accuracy requirements. The vital role of the NSRS continues to grow as society seeks reliable integration and sharing of an ever-expanding array of geospatial data. NGS is currently in the process of modernizing the NSRS, and portions of this manual highlight these changes. As positioning technologies and methodologies evolve, the NSRS modernization will ensure that NGS remains a key partner in surveying and geomatics engineering. This is consistent with what Major Bowie started at ASCE in 1926; and there is no doubt that he would heartily endorse this manual were he alive today. Nearly a century later, this manual is a fitting legacy to Bowie's vision and the ongoing mission of NGS.

Juliana P. Blackwell
Director National Geodetic Survey

PREFACE

In 1985, ASCE published a manual of practice on engineering surveying. It has not been updated since, and the world we are living in today is a very different place when compared with that of 1985. This new reference manual provides a sorely needed and complete update on the modern practice of surveying and geomatics engineering.

In the early 1980s, the digital revolution had just begun with the introduction of the IBM PC. The internet was not widely available, nor was email. In the surveying world, the electronic total station was being introduced, and the US government was just starting to build the Global Positioning System (GPS) satellite constellation.

Today, as some predicted, the use of GPS and other Global Navigation Satellite Systems (GNSS) has become ubiquitous. High-resolution commercial satellites and mobile lidar systems are creating consumer map databases that support vehicle navigation systems in most countries around the world.

As this new Manual of Practice on surveying engineering was being written, mobile computing, autonomous vehicles, augmented and virtual reality, and—perhaps of the greatest potential impact—unmanned aircraft system (UAS) technology were all poised to create the next revolution in surveying and mapping.

None of this would be possible without the surveying engineer who performs work at the intersection of the two fields of surveying and engineering.

For those readers who might be familiar with the 1985 engineering surveying manual of practice, the prologue is an incredibly detailed history of surveying, complete with diagrams and references. I will not even attempt to duplicate that effort. Rather than looking back, it is hoped that this new manual will help establish a vision of the current and near-future role of the surveying engineer.

As stated in the prologue of the previous manual,

Lasers are being tested for acquisition of vertical control in photogrammetry and for providing line and grade in construction related surveying. Similar to radar-equipped Terrain Profile Recorder systems already in use, the laser beam achieves greater precision and resolution in air-to-ground measurement.

This was the early vision for what would become airborne lidar.

It continued,

As a result of the technological breakthrough in surveying and mapping, the survey engineer of the 1980's must be better trained in a much broader field of science than the surveyor of even a decade ago. A background in higher mathematics, computer technology, photogrammetry, geodetic science, and electronics is necessary for today's survey engineer to compete in this rapidly expanding discipline. But like his Nineteenth Century counterpart, the survey engineer should possess those admirable traits of early American character, energy, perseverance and close observation that led some young men who began as axemen and rodmen, to rise in their profession until they became distinguished engineers.

These admonitions in the 1980s are all the more true today. The modern surveying engineer is now faced with an all-encompassing digital suite of sensors and computer software that strain the limits of any practicing professional to keep pace with the changes that are taking place on the technology front. Surveying engineers should seek higher education opportunities and continue learning after graduation to stay abreast with all the latest advancements. With the multitude of changes, many have begun referring to the profession as “geomatics engineering” as it now encompasses a broader field.

Perhaps the greatest challenge facing today’s professionals, from a technical point of view, lies in the shift from 2D, paper-based documentation to 3D digital models that range in scale from an individual project to the entire globe. Satellite navigation systems such as GPS require that the surveying engineer understand the principles of geodesy to judge the accuracy of their 3D positions.

Despite the strong need for more education to keep up with the technology and to support engineering projects, it has been documented that civil engineering university programs are offering fewer courses in surveying and geomatics. Most states allow licensed professional engineers to perform activities associated with surveying engineering; however, many engineers do not necessarily receive the specialized skills, education, and training.

So, this manual is part of a call to action for the engineering community. There are exciting new opportunities for the surveying engineering profession to step up and assume a leadership role as the world struggles with profound changes, including urbanization, climate change, energy demand, decaying infrastructure, and the Internet of Things. These are just a few of the mega trends that require the knowledge and expertise of the surveying engineer.

This manual is intended to provide a foundation for the practice of surveying engineering, but it cannot replace the need for fundamental, continuous education and training because the technology and the profession are not going to stand still. The manual provides background information on the basics of geodesy, least-squares adjustments, error propagation, coordinate systems and transformations, surveying and remote sensing equipment, identification and establishment of control, construction surveying, best practices, and more. Because entire books could be devoted to each of these topics, this manual only provides a summary, and it points the readers to important references where they can find more details. The manual is meant to provide a comprehensive but general overview to help support education and inform practicing engineers on the important role of the surveying engineer. It is too important for this not to occur.

Gene V. Roe

Blue-Ribbon Review Panel

Kevin M. Kelly, Ron Singh, Dave Zilkoski

ACKNOWLEDGMENTS

This Manual of Practice was prepared over a period of several years under the direction of the Surveying Committee of the Surveying and Geomatics Division of the Utility Engineering and Surveying Institute (UESI) of ASCE. Numerous people contributed to the writing, review, and editing of the manual. Thanks to everyone for their service; without their help, this manual would not have come to fruition.

The manual was created following ASCE procedures for creating manuals of practice. First, authors with expertise and experience in a given subject area were invited to draft a chapter. Then, each chapter was sent to a minimum of two experts for peer review. After responding to the review comments and making revisions, the entire draft manual was submitted to three individuals on a Blue-Ribbon Panel to review its overall content. Afterward, the editors made revisions and edits in response to the Blue-Ribbon Panel's review comments. Finally, the manual was sent to the Executive Committee of the Surveying and Geomatics Division and approved for publication. I believe that the expertise of the many authors and the multiple rounds of review have greatly improved the overall quality of the manual.

I would like to thank the following individuals for serving as authors for chapters of the manual; many of these people also helped serve as peer reviewers of other chapters. Special thanks to Dimitrios Bolkas, Michael Bunn, Earl F. Burkholder, Erzhuo Che, Michael L. Dennis, Charles D. Ghilani, N. W. J. Hazelton, Lisa D. Herzog, Jaehoon Jung, Andrew C. Kellie, Matthew S. O'banion, Michael J. Olsen, Chris Parrish, Gene V. Roe, Michael J. Starek, Yelda Turkan, Jan Van Sickle, Marlee A. Walton, Benjamin E. Wilkinson, and David E. Woolley.

I also would like to thank the following people who served as peer reviewers: Steve Breidenbach, Jacky C. K. Chow, Georgia Fotopoulos, David Garber, Chris Glantz, Alec Grkovic, John Hamilton, Steve Hennessee, Brent Jones, Thomas Meyer, Norman Miller, Carol Morman, Jie Shan, Dru Smith, Tomas Soler, Tom Taylor, David Totman, Greg Wear, David Widmer, and Mark Woodson. I am also grateful for the excellent reviews by the three members of the Blue-Ribbon Review Panel: Kevin M. Kelly, Ron Singh, and Dave Zilkoski.

UESI staff provided valuable support and guidance throughout the entire process of creating the manual. Thanks to John Segna, who helped start the process, Diane Swecker, who continued and encouraged its completion, and Susan Reid, who was our primary and most helpful staff support.

Finally, I would like to thank my spirited coeditors who spent countless hours of service meeting, reviewing, revising, and responding to the many important needs required to edit and prepare the final draft of the manual. My most sincere gratitude to Michael L. Dennis and Allan Y. Ng. Your help was invaluable.

*Daniel T. Gillins, Ph.D., P.L.S., Chief Editor
The National Geodetic Survey*

CHAPTER 1

ENGINEERING SURVEYING WITHIN ASCE

Gene V. Roe

INTRODUCTION

ASCE defines engineering surveying as

those activities involved in the planning and execution of surveys for the location, design, construction, operation, and maintenance of civil and other engineered projects. Engineering surveying may be regarded as a specialty within the broader professional practice of engineering and includes all surveying and mapping activities required to support the sound conception, planning, design, construction, maintenance, and operation of engineered projects. Engineering surveying excludes the surveying of real property for the establishment of land boundaries, rights-of-way, easements, and the dependent or independent surveys or resurveys of the public land survey system. ASCE believes that this definition should be adopted by state engineering licensing boards.

These two paragraphs, taken from ASCE Policy Statement 333 (ASCE 2018), define the profession of engineering surveying on which this manual has been written and provided to the public. In addition, we believe that it is important to call the reader's attention to a subtle but critically important distinction in the use of the terms *engineering surveying* and *surveying engineer*. In the first case, we are referring to a type of surveying—an activity. In the second case, it is a type of engineer—an individual. The order in which the terms are used does matter within the profession and particularly when using these terms with the general public. Hence, in this manual, the terms *engineering surveying* and *surveying engineering* should be considered synonymously because they are used interchangeably in many publications. As noted in the following, there are other common phrases for describing this type of surveying activity.

GEOMATICS AND GEOSPATIAL ENGINEERING

The term surveying engineering represents the intersection of the two fields. Many other terms or labels are used to describe this combination of professions, both within and outside the United States. Some of them are discussed as follows.

Since 1926, the Surveying and Geomatics Division has been the lead group within ASCE concerning all topics related to surveying engineering and, more broadly, "mathematics of